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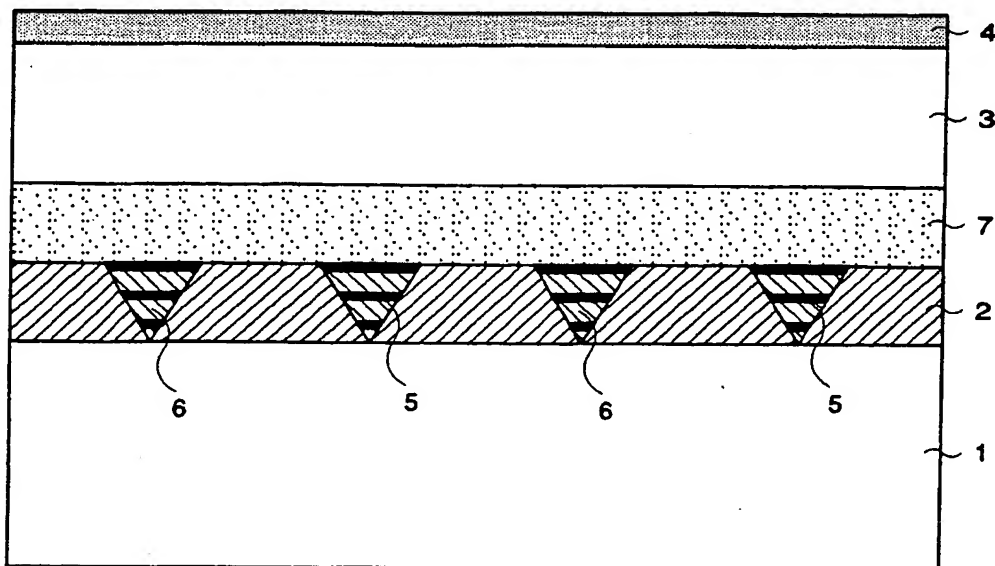
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W-8300 Landshut(DE)(54) **A gain-coupled distributed-feed-back semiconductor laser.**

(57) In a distributed feedback semiconductor laser, the active medium presents a periodic thickness variation in the light propagation direction so as to generate a periodic gain variation, while maintaining the effective refractive index constant, and has a discrete multi-quantum wire structure. A method of manufacturing such a laser is also provided.

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The present invention relates to opto-electronic components for optical communications systems, and more particularly to a gain-coupled distributed-feedback semiconductor laser to be used as a source in one of such systems.

In optical communications systems, and more particularly long-haul communications systems, sources capable of emitting single-frequency signals are of main-interest in order to reduce as much as possible signal distortion due to the different propagation rates of the different frequencies. This condition is essential in case of high-speed direct source modulation and for use in coherent communications systems.

Semiconductor lasers in which optical feedback is obtained by other mechanisms than multiple reflections between the mirrors delimiting the laser cavity are examples of sources meeting the above requirement. In those lasers a selection of the oscillation frequencies (or modes) is obtained without resorting to external components, so that they may be fabricated by integrated-optics circuit technology; moreover, owing to the absence of the end mirrors, the devices are suitable for integration with other components of an optical communications system. Some examples of such lasers are Distributed Bragg Reflector (DBR) lasers and Distributed-Feedback (DFB) lasers. The latter lasers are of simpler manufacture and hence are presently preferred.

Generally, in DFB lasers, optical feedback is obtained thanks to a periodic spatial variation in the effective refractive index (i.e. the refractive index presented by the whole structure for the guided radiation) in the light propagation direction (longitudinal direction). This variation is caused by a grating extending across the whole cavity on or beneath the laser active layer. This optical feedback mechanism is commonly known as "index coupling" and exploits the fact that each refractive index change is accompanied by a weak reflection in the guided radiation: by a suitable choice of the grating period, back reflection will be obtained, and the grating acts as a wavelength-selective mirror, which reflects only the wavelengths closer to that which meets the Bragg condition

$$\Lambda = m \frac{\lambda_B}{2n_v} \quad (1)$$

where

Λ = grating period
 λ_B = Bragg wavelength
 m = grating order
 n_v = mode refractive index

In practice, λ_B is chosen so as to be coincident with the emission wavelength of the laser active layer.

Yet, index-coupled DFB lasers are not per se monomode sources, and their behaviour, in terms of emitted modes, is highly sensitive to reflections on the end facets. More particularly, if those facets are left untreated, the oscillation modes of the laser depend on the relative positions of the facets with respect to the grating spatial phase, which position is entirely casual, since it is impossible to exactly determine at which point a grating will be cut when manufacturing the individual devices. If the laser facets are covered with antireflecting coatings, the laser will steadily oscillate on two modes symmetrical with respect to Bragg wavelength. In the latter case monomodality can be achieved by causing the rays propagating in the laser to undergo a quarter-wave phase shift in the central grating zone. This phase shift is obtained by eliminating a groove of the grating in such a zone, which operation is rather complicated from the technological standpoint. The operations necessary to manufacture a grating presenting the phase shift and to apply the antireflecting coatings cause such a cost increase that generally, in the industrial production of such lasers, it is preferred to keep only lasers which are monomode by fabrication and to discard the others; notwithstanding the elimination of a considerable proportion of the production, this way of operating is still advantageous from the economic standpoint.

The problems of high costs or wastes can be solved by manufacturing a DFB laser where a longitudinal periodic gain variation (gain coupling) occurs instead of a periodic refractive-index variation. It has been theoretically shown (H. Kolgenick, C. V. Shank: "Coupled Wave Theory of Distributed Feedback Lasers", Journal of Applied Physics, Vol. 43, No. 5, May 1972) that a DFB laser is intrinsically a monomode structure and is relatively insensitive to facet reflections, so that no expensive machining such as required for phase-shift introduction in the grating and application of antireflecting coatings is necessary.

An example of gain-coupled DFB laser is described by Y. Luo et al. in the paper entitled "Gain Coupled DFB Semiconductor Laser Having Corrugated Active Layer" presented at the International Conference on Solid State Devices and Materials, Tokyo, August 1988, paper 20DPB-2, and issued on pages 328 - 330 of the proceedings of such Conference. That paper describes a GaAs/GaAlAs laser, comprising, between

conventional confinement layers of GaAlAs (lower and upper claddings), a corrugated layer or grating (pattern-providing layer), this too made of GaAlAs, but with such relative proportions of the constituent elements as to give a refractive index which is high if compared to the lower and upper claddings and is close to that of the active layer; the grating is followed by a further corrugated layer, always made of GaAlAs ("buffer layer"), whose refractive index is low but slightly higher than that of the lower and upper claddings; the active layer of undoped GaAs is deposited on the buffer layer, in such a manner as to obtain a planar structure. In this way a periodic thickness variation is obtained which causes a periodic gain variation. The refractive indices of the various layers and the heights of the teeth of the pattern providing layer and the active layer are chosen so that the effective refractive index keeps constant in longitudinal direction, so as to obtain a laser with pure gain-coupling.

This known structure presents a number of disadvantages due to the presence of a massive active layer, which does not allow attainment of high values not only of the absolute gain, but also of the differential gain (dg/dN , where g = absolute gain, N = number of the injected carriers): as known, the higher the differential gain, the better the spectral line-width characteristics of the laser and more generally the dynamic properties of the device (frequency behaviour, frequency modulation, etc.).

To overcome these disadvantages a semiconductor laser and a method of fabricating same are provided, wherein no massive layer of active material is used, so that good performance can be attained in terms of absolute and differential gain.

In the laser according to the invention, the active material is present only in the grating grooves and consists of discrete layers alternated with layers of a passive material with wider band gap; the layers form in each groove the wires and the barriers, respectively, of a multi-quantum wire structure, oriented perpendicularly to the light propagation direction.

A quantum structure, as known, yields a gain which is some times higher than that of a continuous structure (3 to 4 times higher in case of quantum wells and even higher in case of wires) and, moreover, it yields also a better differential gain. As a consequence, relatively high output powers as well as good dynamic properties can be achieved. It is already known to use to this aim quantum structures, and more particularly multi-quantum well structures, in the active layers of coupled-index distributed-feedback semiconductor lasers. However, such lasers present the drawbacks stated above in respect of the obtention of monomodality. Moreover, one cannot even think to intervene on the already deposited active material to obtain a structure similar to the one suggested according to the invention, with a plurality of discrete multi-quantum wire structures, since, as known, any intervention on the active material causes the occurrence of faults (more particularly, non-radiative recombining centres) in the device.

The invention also provides a method of fabricating a laser according to the invention, wherein a plurality of layers of active material alternated with layers of a passive material with wider band gap are grown in each groove of the grating, so as to form a multi-quantum wire structure orthogonal to light propagation direction, the active and passive layers forming the wires and the barriers, respectively, of said structure.

For a better understanding reference is made to the annexed drawing, which is a longitudinal sectional view of the laser according to the invention.

By way of example the invention is described with reference to a laser made of InP/InGaAs/InGaAsP; the description also applies in case of a laser using different constituent elements, e.g. GaAs/GaAlAs.

The laser of the invention comprises, in conventional manner, a substrate 1 of suitably doped InP (e.g. n-doped), a grating 2 of quaternary InGaAsP alloy, the upper cladding 3 of InP doped in opposite manner to layer 1 (hence p-doped) and a contact layer 4 of highly-p-doped InGaAsP, allowing electrode application. Grating 2 has a period satisfying the above mentioned Bragg condition; besides, the constituent element proportions in the quaternary alloy of which the grating is made are chosen so as to yield a refractive index satisfying determined conditions which will be reported hereinafter.

The optically active material is present only in the grating grooves and consists of discrete layers 5 of InGaAs, separated by layers 6 of a passive material of wider band gap, e.g. InP or an InGaAsP alloy: layers 5,6 are made so as to form the wires and the barriers of a quantum wire structure. The thicknesses of the layers of active material are chosen so as to provide the desired emission wavelength (e.g. 1.55 μm). This thickness, as known, is perfectly determined once the materials forming the wires and the barriers are determined.

The number of layers 5 is chosen in the design step so as to optimise laser performance. More particularly, such number is chosen so as to meet the so-called threshold condition, according to which mode gain must be equal to losses. This condition is expressed by relation

$$\Gamma \cdot g = \alpha_t$$

where

- Γ = optical confinement factor, i.e. the part of the electromagnetic field contained in one layer;
 g = active material gain
 α_t = total losses.

As known, gain g of a quantum structure is a few times higher than that of a massive structure. The confinement factor is on the contrary lower. By varying the number of the layers one can hence change Γ so as to satisfy the above condition.

When optical confinement increase is desired, a further layer 7 of quaternary InGaAsP alloy can be provided upon the grating and the quantum-wire structure. The thickness of layer 7 is determined in the design step in order to increase Γ and make meeting of the threshold condition easier.

It is clear that the described structure presents a periodic gain variation, since the active material is present only in the grating grooves. Making the active layer as a multi-quantum wire structure ensures the advantages in terms of absolute and differential gain inherent in this type of structure.

In order to fabricate the laser described, once grating 2 is formed with the techniques generally used to this aim in DFB laser fabrication (more particularly holography or electron beam lithography), quantum wires are grown in the grating grooves. To this aim the techniques commonly used to fabricate quantum well or quantum wire structures can be adopted, e. g. molecular beam epitaxy or vapour phase deposition (or vapour phase epitaxy) of organometallic compounds. Care has to be taken in order to fabricate quantum structures only in the grooves or at least to ensure an easy removal of material of such structures grown outside the grooves. E.g., if the surface of grating 2, in zones between grooves, is kept covered, during the operations leading to the growth of the quantum structures, with the photoresist layer applied during etching operations, the material of quantum structures possibly grown on such layer has a polycrystalline structure instead of a crystalline one, and hence is easy to remove, as is well known to the skilled in the art.

It is important to avoid growth of quantum structure material on the grooves walls since that would cause active material continuity inside the groove and hence would annul the advantages deriving from the presence of a discrete structure: this can be made easier if the grooves, instead of being exactly V-shaped, have a non null width in the zone corresponding to the vertex.

The successive layers are then made in a fully conventional manner; also lateral light confinement is obtained in quite conventional manner, by making a ridge structure or a buried structure.

To ensure monomodality, the laser must present gain coupling alone, without index coupling. To obtain this, the grating material composition must be chosen so that the effective refractive index n in the zones where there are no quantum structures satisfies relationship

$$N = \frac{N_w \cdot t_w \cdot n_w + N_b \cdot t_b \cdot n_b}{N_w \cdot t_w + N_b \cdot t_b} \quad (2)$$

where: N_w , N_b are respectively the number of quantum wires and barriers; t_w and t_b are the wire and barrier thicknesses; n_w , n_b are the refractive indices.

It is always possible to find a quaternary InGaAsP alloy with refractive index n meeting condition (2), since, as known, refractive index in such alloys varies with continuity from the value corresponding to InGaAs to that corresponding to InP when varying the proportions of Ga, As and P. Relation (2) clearly indicates that, in case a quaternary InGaAsP alloy is used to make the barriers, its composition shall be different from that of the alloy used for the grating.

What described applies also to lasers made of GaAs/GaAlAs. In such case quantum wires 5 are made of GaAs and barriers 6 of GaAlAs. Grating 2, in order to satisfy condition (2) for the refractive index, will be made of a GaAlAs alloy of a composition capable of yielding a lattice parameter different from that of the layer on which it is grown ("strained" material).

Claims

1. A gain-coupled distributed-feedback laser, wherein optical feedback is obtained by means of a grating (2) of passive semiconductor material extending along the whole laser length, with reference to light propagation direction, and wherein the active medium has a periodically changing thickness so as to introduce a periodic gain variation, characterized in that the active medium is present only in the grooves of the grating (2) and comprises discrete layers (5) alternated with layers (6) of a semiconductor material of different band gap, which layers form in each groove respectively the wires and the

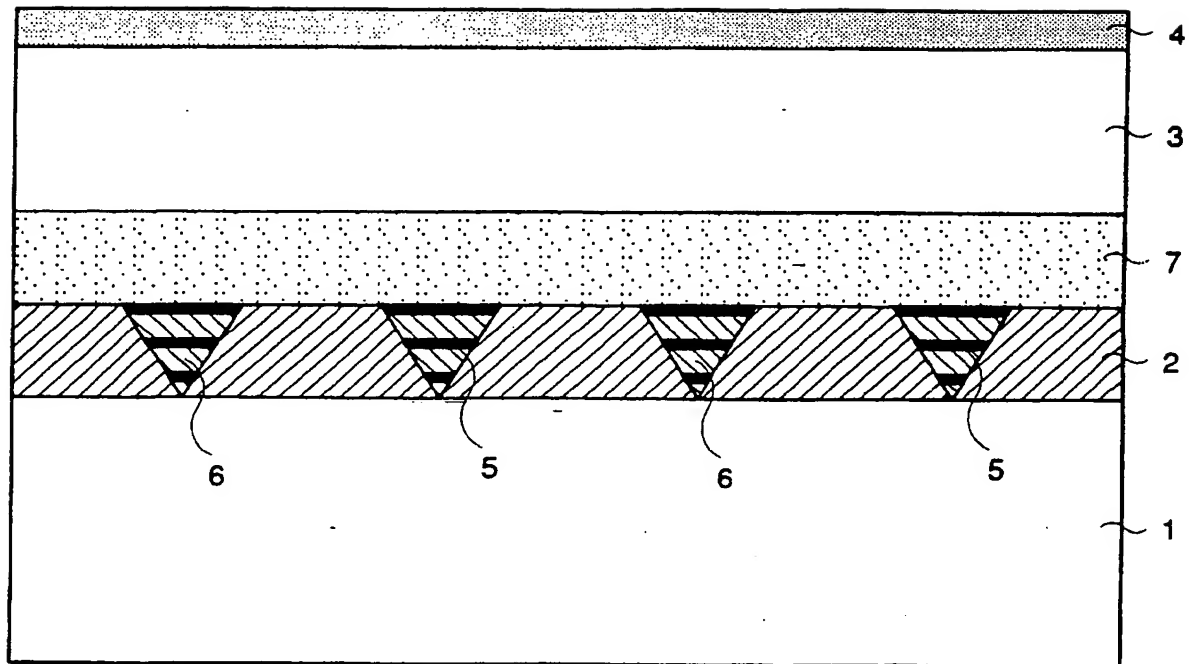
barriers of a multi-quantum wire structure, oriented perpendicular to light propagation direction.

2. A laser as claimed in claim 1, characterised in that an optical confinement layer (7) is provided on the grating (2) and the multi-quantum wire structure.
3. A laser as claimed in claims 1 or 2, characterised in that the grating (2) is made of a material whose refractive index is such that the effective refractive index, outside the grooves, satisfies condition

$$N = \frac{N_w \cdot t_w \cdot n_w + N_b \cdot t_b \cdot n_b}{N_w \cdot t_w + N_b \cdot t_b}$$

where N_w , N_b is the number of wires and of barriers respectively; t_w , t_b are the thicknesses of the wires and the barriers respectively; n_w , n_b are the refractive indices of the wires and the barriers respectively, so as to ensure the constancy of the effective refractive index in light propagation direction.

4. A method of fabrication of a laser as claimed in any preceding claim, in which on a layer (1) of a first passive semiconductor material a grating (2) of a second passive material is formed, characterised in that a plurality of layers (5) of active material separated by layers (6) of a further passive material with a wider band gap are grown in each groove of the grating (2), so as to form a quantum wire structure orthogonal to the light propagation direction.
5. A method as claimed in claim 4, characterised in that, said grooves have a non-zero width in correspondence with their vertices, to avoid active material growth on groove walls.
6. A method as claimed in claims 4 or 5, characterised in that, while growing the quantum wire structures, the surface portions of the grating (2) between adjacent grooves are kept covered with a photoresist layer interacting with the quantum wire material to confer it a structure allowing an easy removal of such material possibly grown outside the grooves.
7. A method as claimed in any one of claims 4 to 6, characterised in that an optical confinement layer is deposited on the grating and quantum wire structures.





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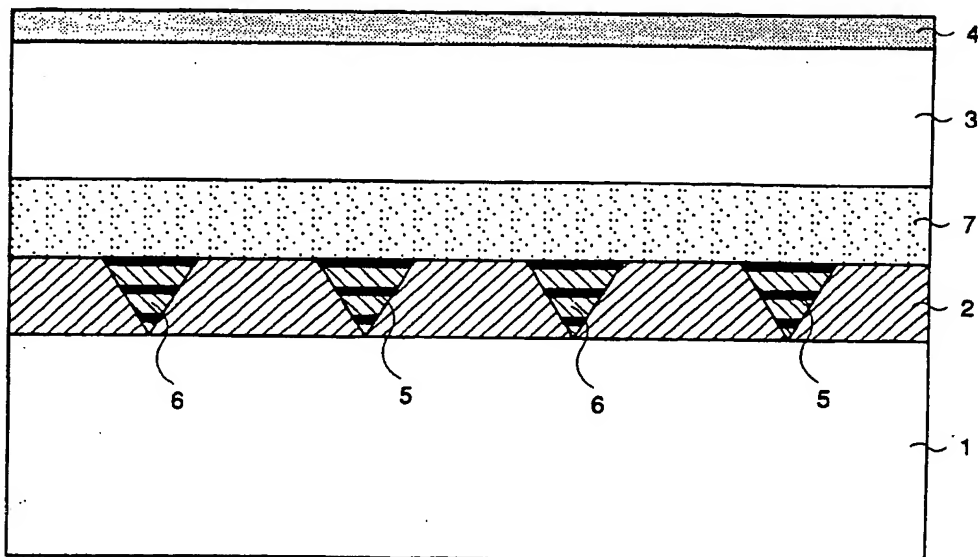
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X	PATENT ABSTRACTS OF JAPAN vol. 13, no. 346 (E-798)3 August 1989 & JP-A-11 06 489 (FUJITSU LTD) * abstract *	1	H01S3/085 H01L33/00 H01S3/06 H01S3/19
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 05 OCTOBER 1992	Examiner CLAESSEN L.M.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			



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The present search report has been drawn up for all claims			
Place of search THE HAGUE	Date of completion of the search 05 OCTOBER 1992	Examiner CLAESSEN L.M.	
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons Δ : member of the same patent family, corresponding document			

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